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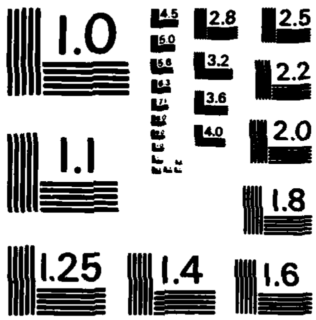

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Technical Report

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D.C. Weikle

Earth Coverage Corrugated Horns (44.5 GHz and 20.7 GHz)

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Lincoln Laboratory

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

EARTH COVERAGE CORRUGATED HORNS
(44.5 GHz and 20.7 GHz)

D.C. WEIKLE
Group 61

TECHNICAL REPORT 656

19 JULY 1983

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LEXINGTON MASSACHUSETTS

ABSTRACT

Communications satellites located in geosynchronous orbits will, in addition to more specialized shaped beam or area coverage antennas, generally utilize earth coverage antennas designed to maximize antenna gain over the entire surface of the visible earth. In the microwave and millimeter wave bands, these antennas are usually conical horns which achieve a minimum gain (G_{min}) of 17 - 17.5 dBi at the limb of the earth. This paper describes the design of a single mode (HE_{11}) earth coverage horn that optimizes G_{min}. Measurements performed over a 5% frequency band on experimental models designed to operate at 20.7 GHz and 44.5 GHz demonstrate a G_{min} 17.8 dBi. Other characteristics of the horns are circularly symmetric radiation patterns, low VSWR (1.2), and peak gain of approximately 22.0 dBi.

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I. INTRODUCTION

The figure of merit for a satellite antenna designed for full earth coverage is the minimum directive gain (G_{min}) that occurs anywhere within the coverage area. For an antenna with a conventional radiation pattern (non-shaped beam), G_{min} occurs at the edge of earth (EOE) position. This report describes a single mode (HE_{11}) corrugated horn design which optimizes the horn aperture size to produce the maximum EOE gain (as viewed from geosynchronous altitude). The EOE is located approximately 8.6° from the boresight of an antenna pointed directly at the center of the earth. However, to provide for spacecraft attitude instabilities, 9° was used as the EOE angle.

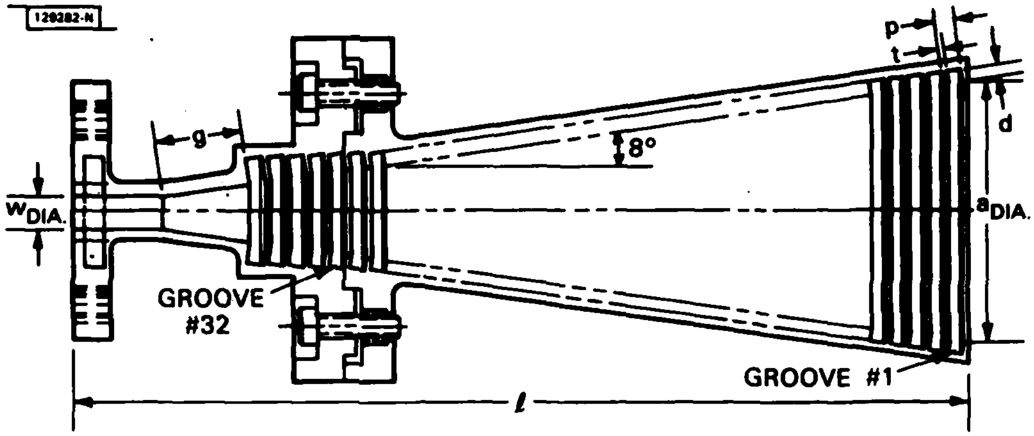
II. DESIGN

The aperture size producing the maximum gain at 9° was determined by calculating the gain of various aperture sizes of an HE_{11} mode horn and determining the optimum.[1] The maximum value of EOE gain is obtained with an aperture diameter of 4.99 λ_o (λ_o = free space wavelength). Corrugated horns utilizing this optimum aperture size then were designed for operating frequencies of 20.7 GHz and 44.5 GHz (see Fig. 1).

Circumferential corrugations on the inner walls of the horns are used to generate the HE_{11} mode in order to obtain circularly symmetric radiation patterns. These grooves are spaced approximately 0.38 λ_o apart and are separated by a 0.1 λ_o wall (dimensions p and t in Fig. 1). The depths of the first five corrugations nearest the throat are tapered[2] to provide a good impedance match between the TE_{11} and HE_{11} propagation regions. The groove depth of the remaining corrugations is 0.25 λ.

With a given aperture size, the phase deviation from a plane in the aperture is determined by the cone angle. Larger cone angles result in higher sidelobe levels and reduced beam efficiency. Smaller cone angles, however, result in increased overall length of the horn and increased difficulty in fabrication. In the present design, a cone angle of 8° with a consequent phase deviation of 0.175 λ was selected. This corresponds to a reduction in aperture efficiency of approximately 3% relative to an aperture with no phase deviation.

Since the deepest corrugations are located near the throat of the horn, they are the most difficult to machine. To ease the fabrication process, a



DIMENSION	20.7 GHz	44.5 GHz
a	2.844	1.323
ℓ	9.00	4.50
p	0.217	0.101
t	0.054	0.025
g	0.954	0.442
w	0.404	0.188

DIMENSION d GROOVE NO.	20.7 GHz	44.5 GHz
1 THRU 31	$0.142\ ^{+0.005}_{-0.000}$	$0.066\ ^{+0.005}_{-0.000}$
32	0.163	0.076
33	0.185	0.086
34	0.206	0.096
35	0.228	0.106
36	$0.249\ ^{-0.000}_{+0.005}$	$0.116\ ^{+0.005}_{-0.000}$

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Fig. 1. Earth coverage corrugated horn design (20.7 and 44.5 GHz).

section of the cone in the throat of the horn was not corrugated. The length of this section (g), determined empirically, was chosen carefully. If g is too large, the diameter of the horn at the first corrugation will be large enough to allow the excitation of higher order modes. The value of g also influences the VSWR which depends upon the addition of two dominant reflections: the reflection at the horn throat junction and the reflection at the onset of corrugations.[3] The length of g chosen for the EC horns is 1.67 λ.

III. FABRICATION

Initially, the development earth coverage horns were fabricated in a one-piece construction using the electroformed copper process (see Fig. 2). This process was chosen because the corrugations, which are difficult to machine and measure accurately (especially the ones nearest the throat), can be controlled precisely by electroforming. In this way, design modifications could be made in the development models and their effects clearly understood. However, electroforming can be undesirable for two reasons: 1) weight and perhaps more important, 2) electroforming solution sometimes becomes trapped in the corrugation walls. This solution can leak out into the corrugations where it solidifies, affecting the performance of the horn. Therefore, while the electroformed horns served as a useful development tool, the final versions of the horns were fabricated in a two-piece, machined, aluminum construction (Fig. 3). The two-piece construction eased machining by allowing easier access to the throat region of the horn. Three horns were fabricated* for an operating frequency of 20.7 and two for 44.5 GHz at a cost of less than $1,000 each. These horns are considered to be flight quality and have weights of 286 grams and 78 grams for the 20.7 GHz and 44.5 GHz versions, respectively.

*The horns were fabricated by P&L Machine, Acton, Mass.

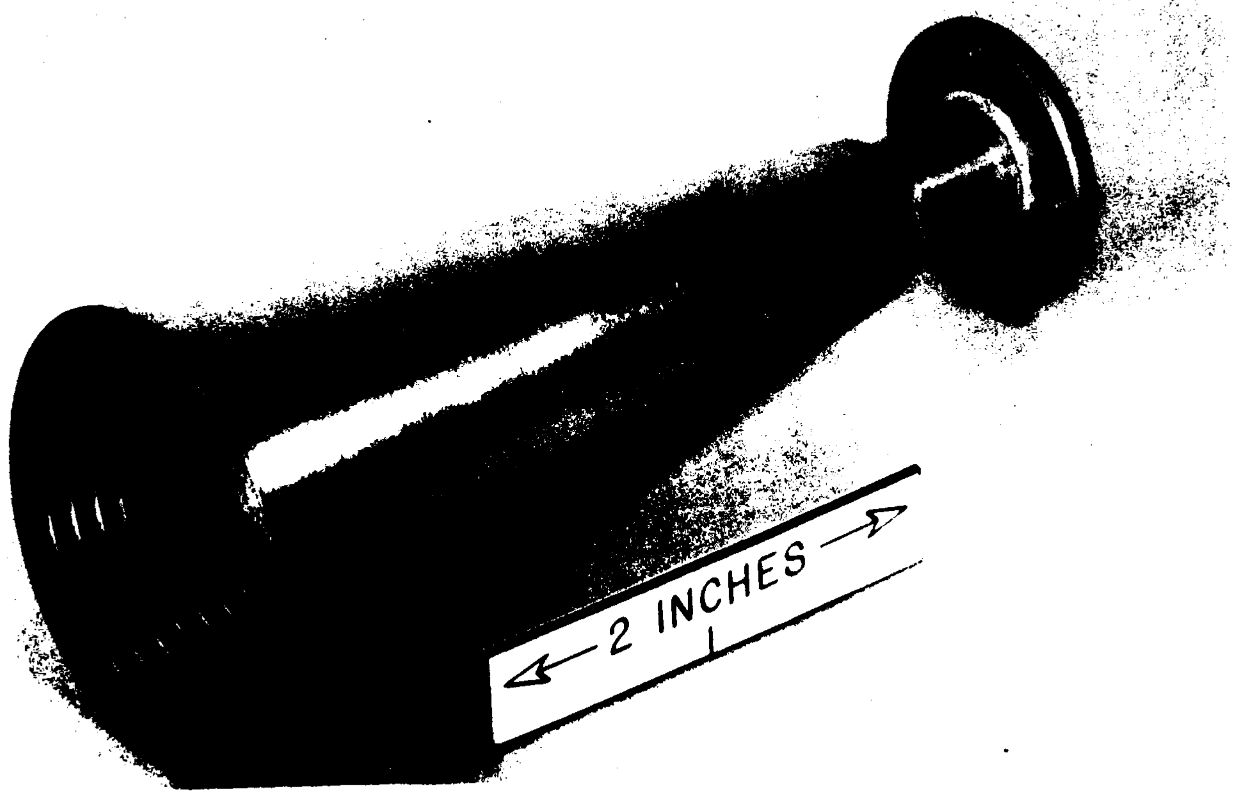

Fig. 2. 44.5 GHz electroformed earth coverage horn.

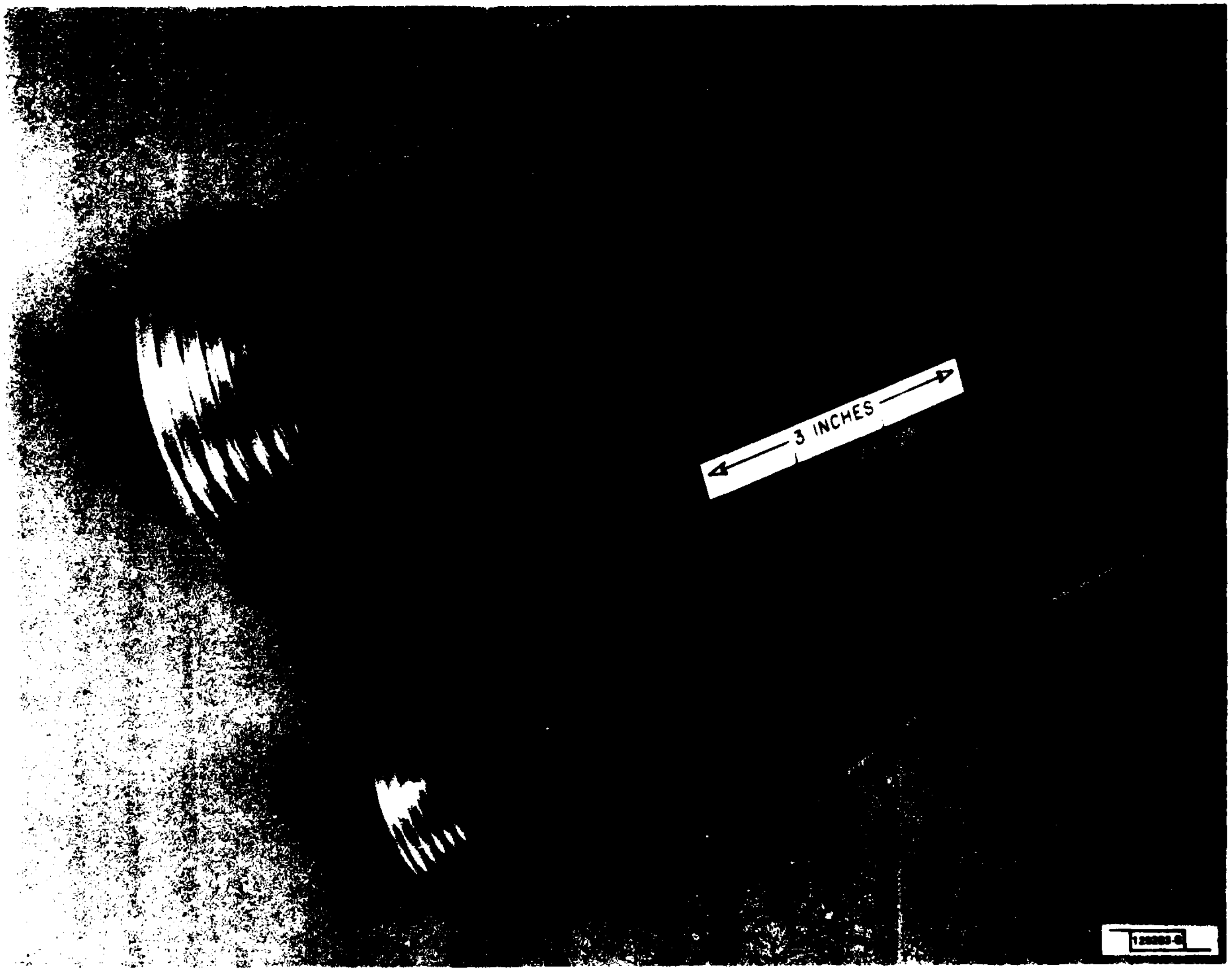

Fig. 3. Earth coverage horns — two-piece construction.

IV. MEASUREMENTS

Radiation pattern, gain, and VSWR (return loss) measurements were performed on the earth coverage horns over a 5% frequency band. The gain and radiation pattern measurements were conducted on a 25-ft. range. Radiation patterns were taken at three discrete frequencies covering the respective band of each horn while the gain and VSWR were measured in one continuous frequency sweep. The gains of the horns were determined by comparisons with gain standard horns.

Since the 20.7 GHz and 44.5 GHz horns are scaled versions of one another, their performance is virtually identical. The radiation patterns presented are those performed on a 44.5 GHz horn (two-piece construction), although the patterns are typical of horns designed for either frequency. A measured 44.5 GHz radiation pattern is shown in Fig. 4. (Note - EOE position is -4 dB from peak). To easily observe the axial symmetry, the E- and H-plane radiation patterns are superimposed onto one another. The beamwidth and sidelobe levels agree very well with the theoretical, computer-generated pattern shown in Fig. 5. Measured patterns taken at 43.5 GHz and 45.5 GHz are shown in Figs. 6 and 7, respectively.

The on-boresight swept gain measurement is shown in Fig. 8. At 44.5 GHz, the on-axis gain measured 22.1 dBi which yields an edge of earth gain of approximately 18.1 dB. The EOE gain also was measured by scanning the horn 9° off boresight in the H-plane and the amplitude level compared to that of the gain standard (Fig. 9). Here the EOE gain measured 18.0 dBi at 44.5 GHz. The minimum EOE gain occurs at 43.5 GHz and is 17.8 dBi.

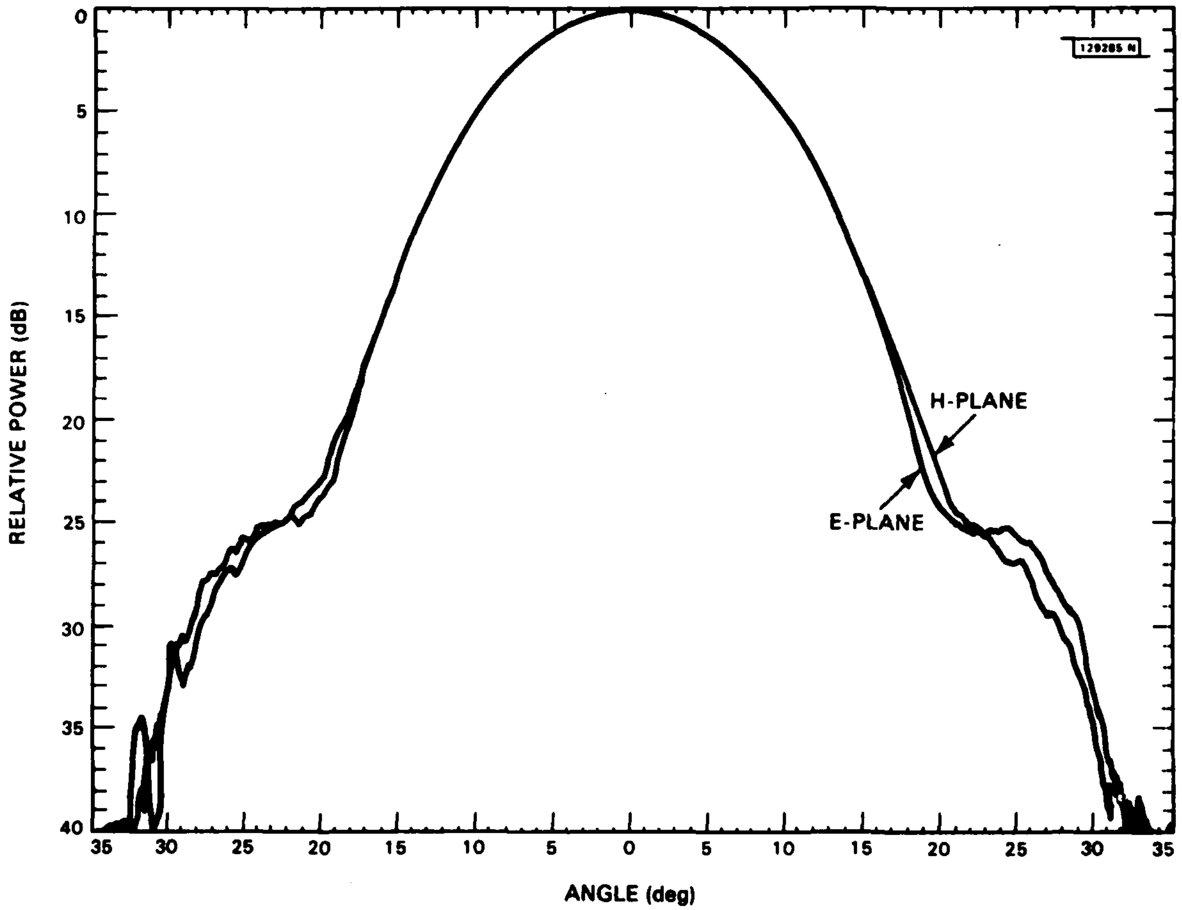

Fig. 4. Measured radiation pattern of earth coverage horn — 44.5 GHz.

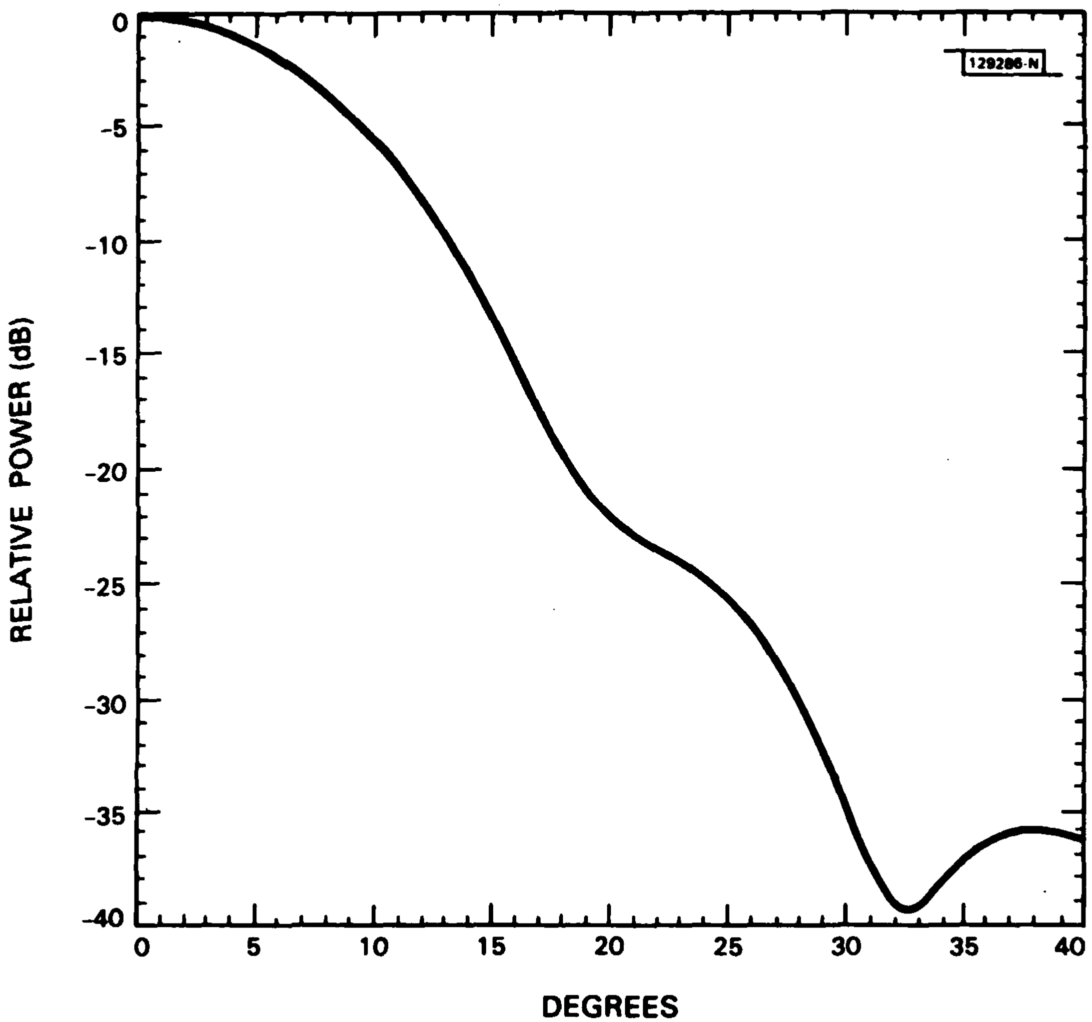

Fig. 5. Computer-generated pattern — 44.5 GHz.

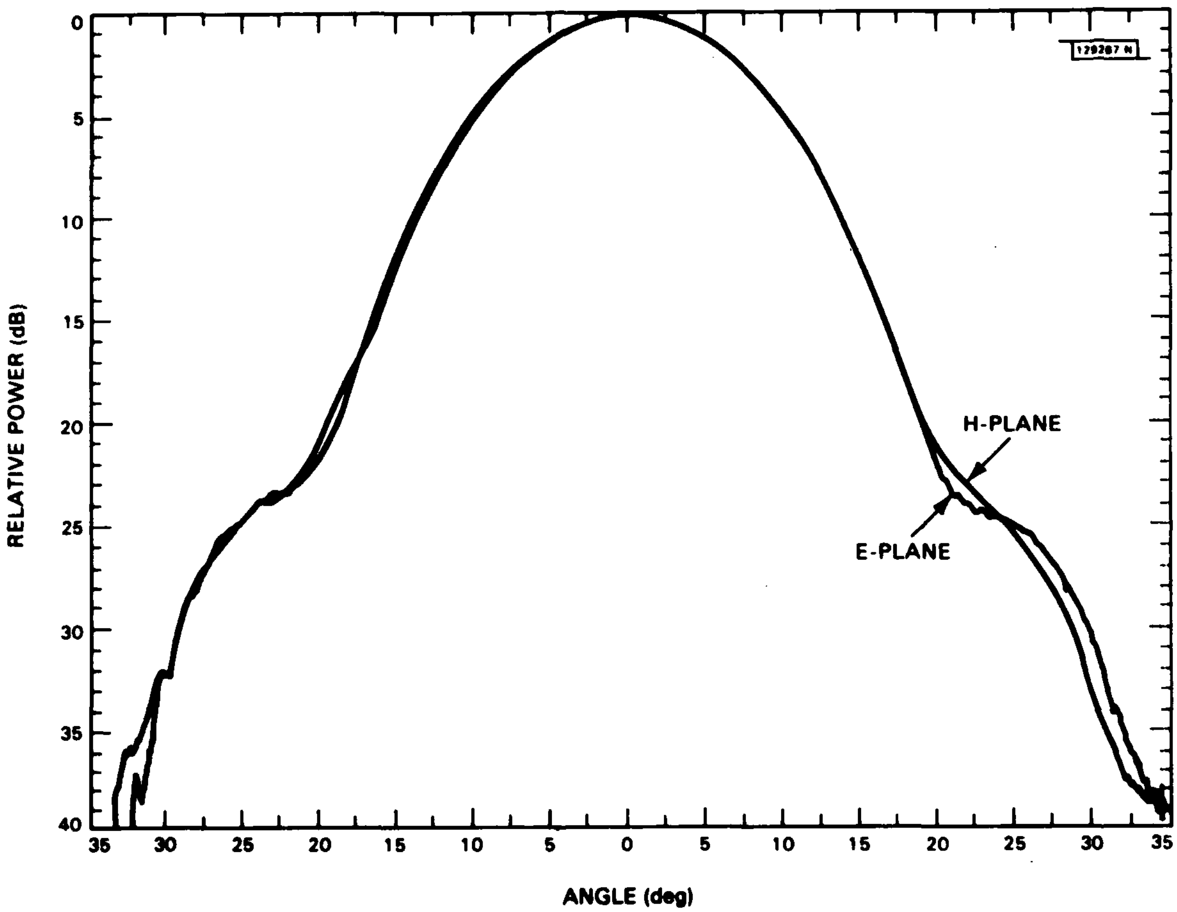

Fig. 6. Measured radiation pattern of earth coverage horn — 43.5 GHz.

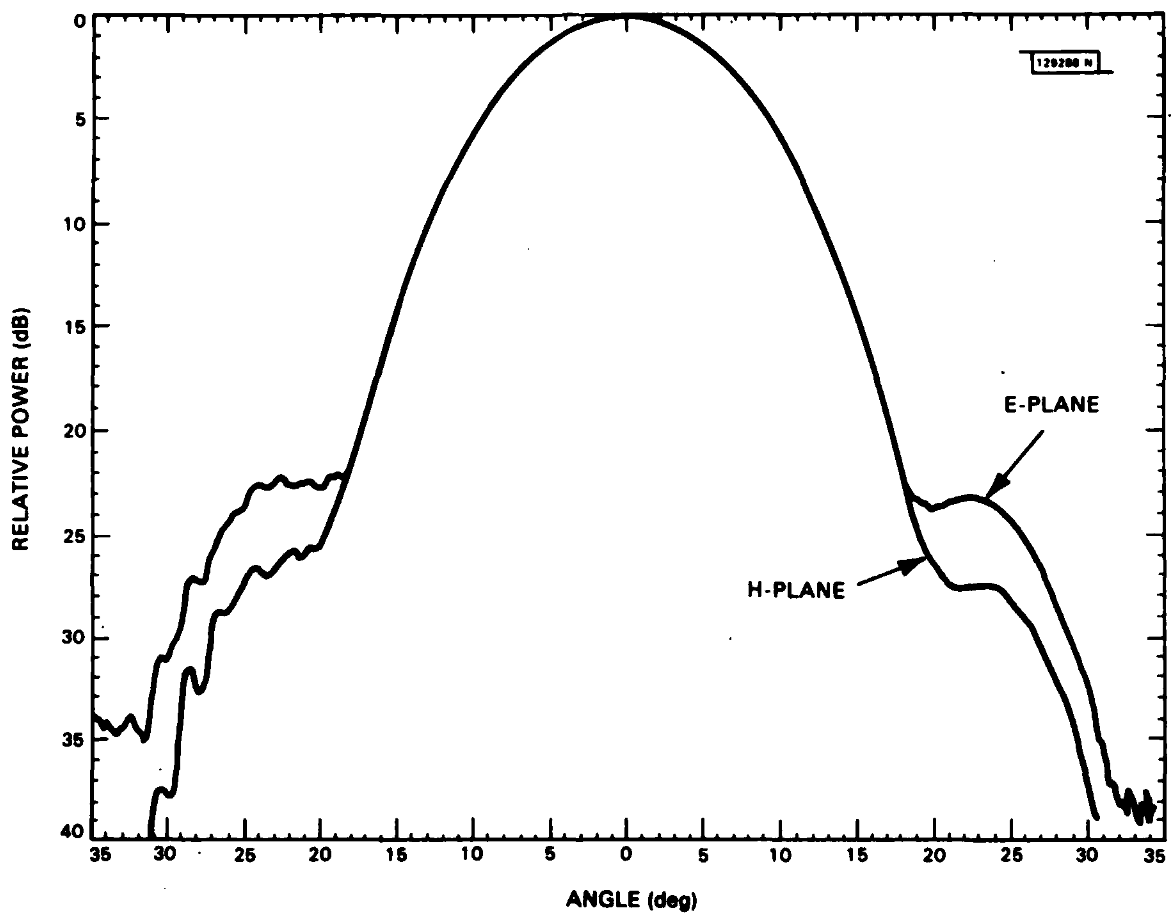

Fig. 7. Measured radiation pattern of earth coverage horn — 45.5 GHz.

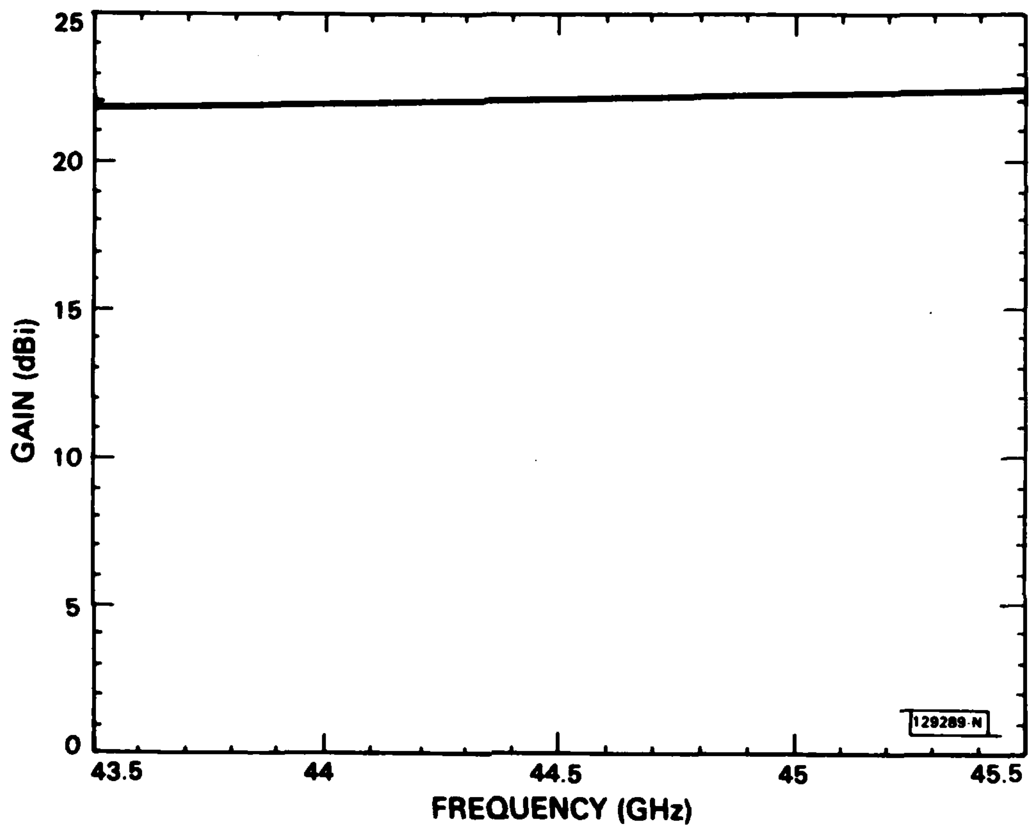

Fig. 8. Measured on-boresight swept frequency gain (43.5 — 45.5 GHz).

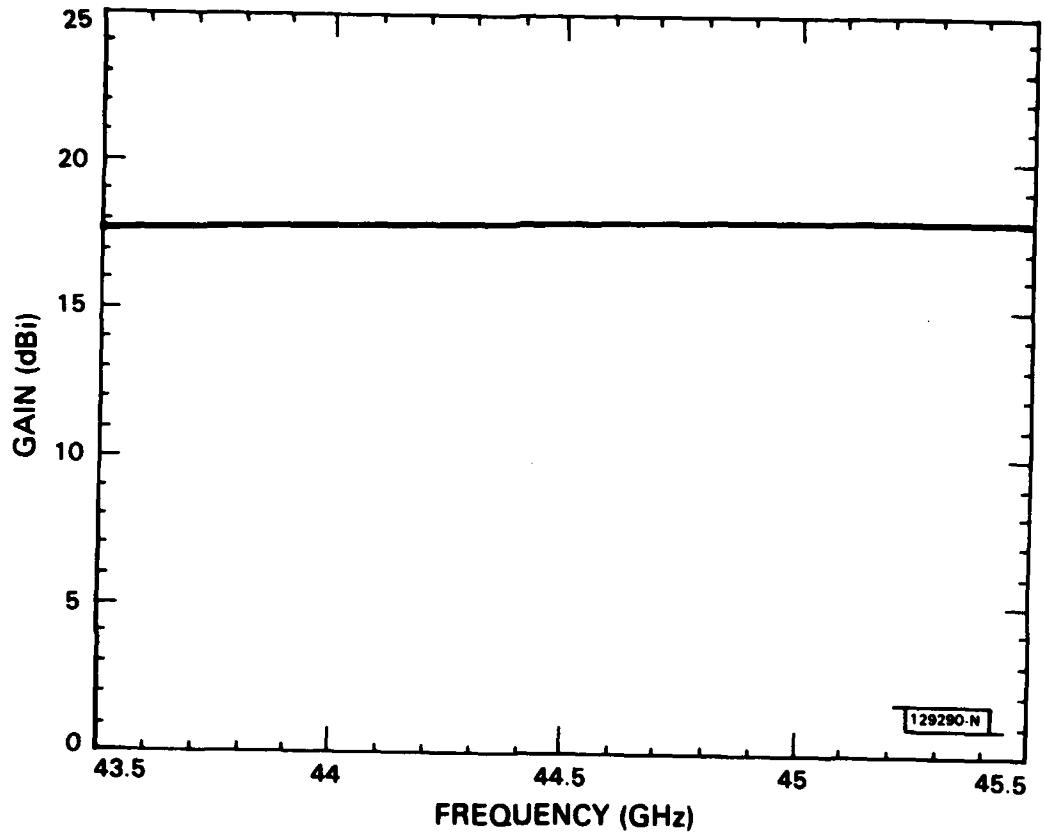

Fig. 9. Measured 9° off-boresight swept frequency gain (43.5 – 45.5 GHz).

A typical swept frequency VSWR measurement is shown in Fig. 10. Of the five horns measured, the VSWR within the frequency band is typically less than 1.2. A listing which summarizes the gain and VSWR measurements on all five horns is shown in Table 1. The minimum column in the gain table and the maximum column in the VSWR table indicates the maximum and minimum values that occurred over the frequency band.

Figure 11 shows a spinning linear radiation pattern of a circularly polarized 20.7 GHz earth coverage horn. The horn was circularly polarized by attaching an external sloping septum polarizer* to its circular waveguide port. Th^ axial ratio within the included angle of ±9° from boresight is less than 0.4 dB and is typical of measurements performed at three frequencies over the band.

*Polarizer manufactured by Atlantic Microwave, Bolton, Mass.

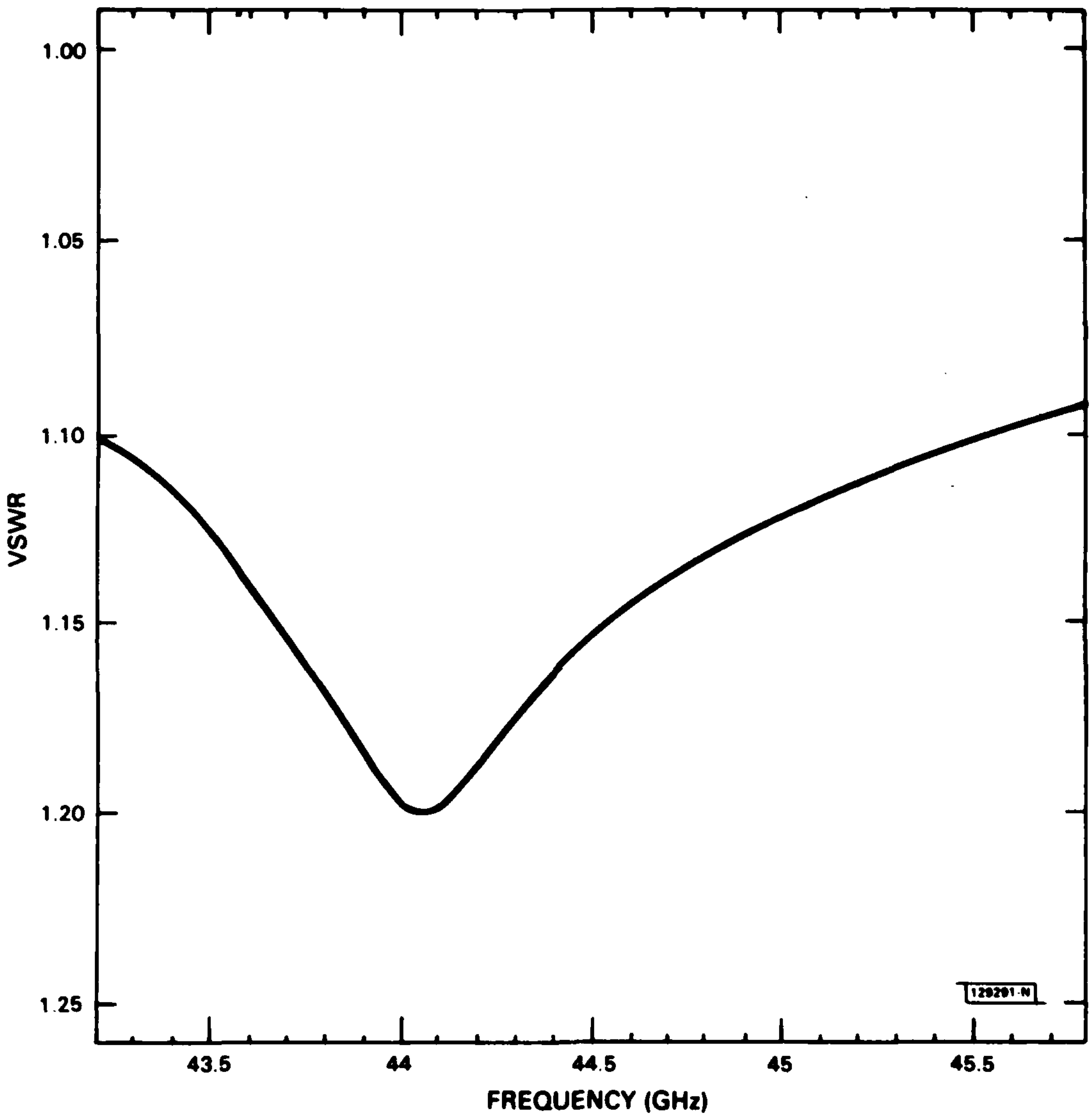

Fig. 10. Measured swept frequency VSWR (43.5 — 45.5 GHz).

TABLE 1

EARTH COVERAGE HORN PERFORMANCE SUMMARY

	SER. No.	EOE GAIN (dBi)				PEAK GAIN (dBi)				VSWR			
20.7 GHz EC HORN	////	20.2 GHz	20.7 GHz	21.2 GHz	MIN	20.2 GHz	20.7 GHz	21.2 GHz	MIN	20.2 GHz	20.7 GHz	21.2 GHz	MAX
	1	18.1	17.8	17.8	17.8	22.1	22.2	22.4	22.1	1.21	1.10	1.06	1.21
	2	18.1	17.9	17.8	17.8	22.1	22.2	22.4	22.1	1.20	1.10	1.06	1.20
	3	18.1	17.9	17.8	17.8	22.0	22.1	22.4	21.9	1.20	1.10	1.05	1.20
45.5 GHz EC HORN	////	43.5 GHz	44.5 GHz	45.5 GHz	MIN	43.5 GHz	44.5 GHz	45.5 GHz	MIN	43.5 GHz	44.5 GHz	45.5 GHz	MAX
	1	17.8	18.0	17.9	17.8	21.9	22.1	22.6	21.9	1.15	1.10	1.05	1.21
	2	17.8	17.9	17.9	17.8	21.9	22.1	22.5	21.9	1.15	1.10	1.05	1.19

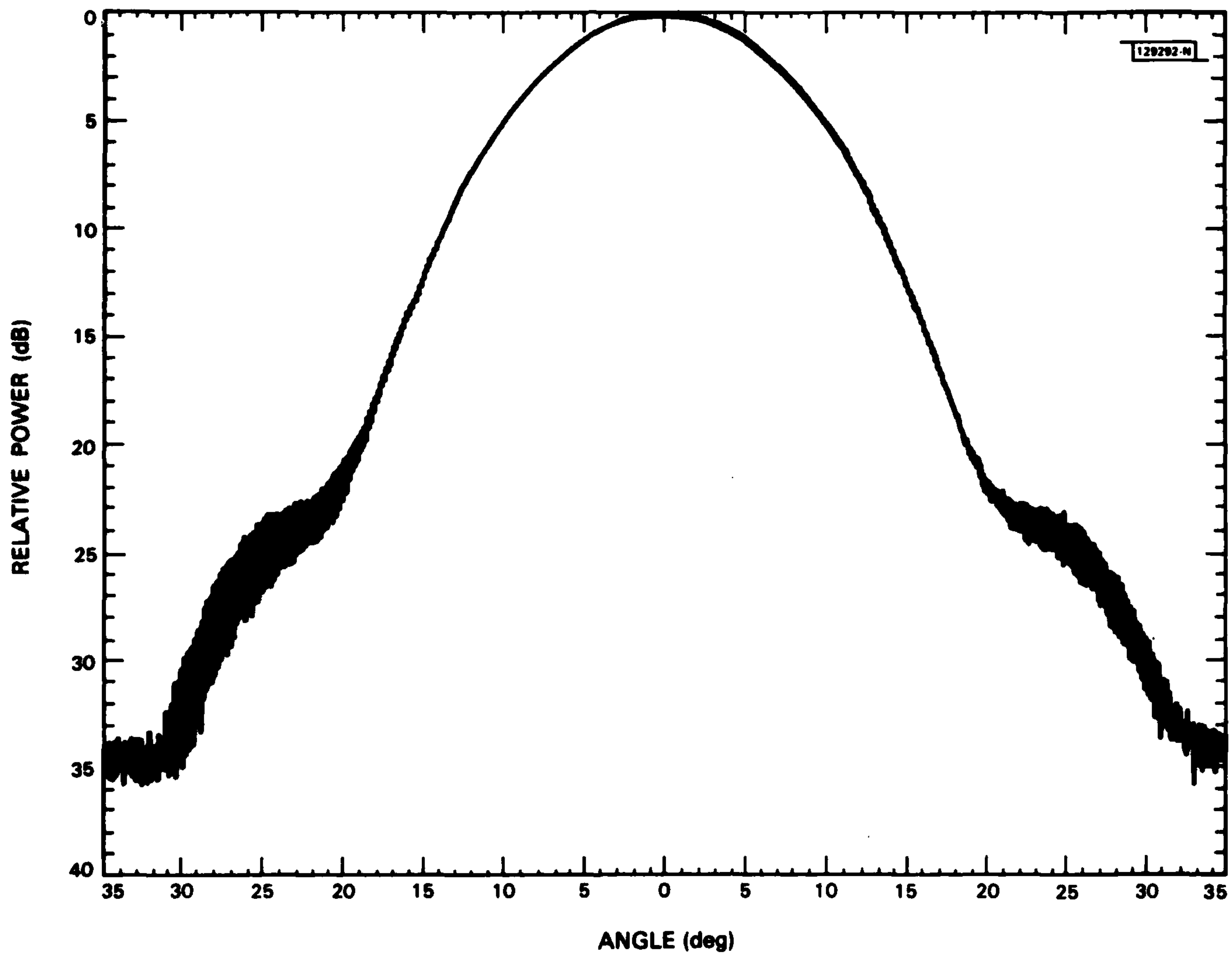

Fig. 11. Spinning linear radiation pattern of 20.7 GHz circularly polarized earth coverage corrugated horn.

V. CONCLUSIONS

A single mode earth coverage corrugated horn was designed to optimize the minimum gain (G_{min}) within the earth field of view (as viewed from geosynchronous altitude). Experimental models built at operating frequencies of 20.7 GHz and 44.5 GHz were evaluated over a 5% frequency band for each horn. Measured G_{min}, which occurs at the edge-of-earth position (±9° from boresight), is 17.8 dBi which is very close to the theoretical maximum for a horn with a conventional radiation pattern (non-shaped beam). The horns also produced circularly symmetric radiation patterns and VSWR of approximately 1.2. The aperture diameter is approximately 5 λ, the overall length is 17 λ, and the weight is 286 grams and 78 grams for the 20.7 GHz and 44.5 GHz horns, respectively.

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3. S. F. J. Melo, "Improved Primary Radiator for the 11 GHz Band," Electrical Communication, 54, No. 2 (1979) p. 125.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Communications satellites located in geosynchronous orbits will, in addition to more specialized shaped beam or area coverage antennas, generallly utilize earth coverage antennas designed to maximize antenna gain over the entire surface of the visible earth. In the microwave and millimeter wave bands, these antennas are usually conical horns which achieve a minimum gain (G_{min}) of 17 - 17.5 dBi at the limb of the earth. This paper describes the design of a single mode (HE_{11}) earth coverage horn that optimizes G_{min}. Measurements performed over a 5% frequency band on experimental models designed to operate at 20.7 GHz and 44.5 GHz demonstrate a G_{min} 17.8 dBi. Other characteristics of the horns are circularly symmetric radiation patterns, low VSWR (1.2), and peak gain of approximately 22.0 dBi.

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